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(54) Title: COMPOSITE MONOLITHIC LAP AND A METHOD OF MAKING THE SAME

(57) Abstract

A composite yet monolithic abrasive material-removing lap includes a sintered porous matrix of ceramic or metal material and a quantity of an impregnating material substantially completely filling the pores of the sintered porous matrix preform at least throughout an effective region of the lap that is to come in contact with a workpiece to be acted upon by the lap. The lap is made by first slip-casting a preform, then freezing and freeze-drying the same, followed by lightly sintering the dry preform into a porous matrix preform, bringing the temperature of the preform to above the temperature at which the impregnating material is flowable, and filling the pores with the impregnating material.

M { porosity
particle size
thermal conductivity.

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Description

Composite Monolithic Lap and a Method of Making the Same

Technical Field

The present invention relates to the manufacture of ceramic articles in general and more particularly to the manufacture of grinding and/or polishing laps and similar tools.

Background Art

There are already known various constructions of laps for use in grinding and/or polishing, among them such especially suited for performing such operations on mirrors, lenses and similar optical components. Because of the relative delicacy of the components of this kind and the need to achieve as high a degree of accuracy as possible, both in terms of surface quality and figure conformity, such laps have to possess certain characteristics that greatly affect the material removal process from the workpiece and that have to be properly chosen for the respective application. One of such characteristics is the stiffness of the lap or a similar grinding and/or polishing tool. The stiffness affects the depth of penetration of the abrasive particles into the lap or tool and, correspondingly, the depths of the cuts made thereby in the workpiece. High stiffness results in deeper cuts with faster material removal, but also in greater damage, especially when the workpiece is of a brittle material. Stiffness of the tool also affects the figure control achieved during the material removal operation in that stiffer laps control the figure

better than more compliant ones. Another one of the important characteristics is the thermal conductivity of the tool in that it affects the surface temperature of the workpiece which, in turn, affects the figure control and possibly even the chemistry of the material removal process. Yet another important characteristic is the hardness of the lap or similar tool in that it determines the extent to which abrasive particles adhere to the tool.

Experience has shown that it is very difficult if not impossible to satisfy all of the requirements for the grinding or polishing operation in a particular application with a monolithic lap, especially since at least some of the above requirements are contradictory to one another in the sense that a change in one of the characteristics to better satisfy one of the above requirements usually has a deleterious effect on the satisfaction of another requirement. Consequently, in the past, the monolithic lap or similar tool material selection was often a matter of compromise, weighing the importance of the various requirements against each other, and selecting the tool material for best achievable (but not ideal) performance. Typically, such compromise lap materials for use in grinding or polishing optical components are, on the one hand, relatively soft materials, such as pitch, that are charged with the desired abrasives, for example by pressing the soft material body of the respective lap against the workpiece with a layer of the abrasive being interposed between the body and the workpiece. In many instances, the soft material body has an increased overall rigidity imposed thereon by being mounted in or on a high-rigidity support or backing element. However, even this latter expedient does not overcome the deleterious effects of the relatively high yieldability of the lap body material at the region

closest to the workpiece on the figure of, and on the penetration depth of the abrasive particles into, the workpiece.

On the other hand, it was also proposed to resort to so-called free abrasive grinding where the abrasive particles are not and do not become embedded in the grinding lap. Then, attempted to approach or achieve the desired overall results by using a plurality of laps of different materials in such a manner that different laps were used during different phases of the respective free grinding operation and/or for different applications. This, of course, brought about a situation that was disadvantageous in the respect that it resulted in the needs for making or purchasing, and for storing, the aforementioned plurality of different laps, for carefully selecting and locating the lap to be used during the particular grinding operation phase or in the particular application, and for replacing the respective previously used laps with the new ones. Typically, the materials of choice for such laps for use in free abrasive grinding of optical components have been various relatively hard materials, such as various grades of glass, ceramic tiles and metals exhibiting various degrees of rigidity. In some instances, the hard material body has an increased overall rigidity imposed thereon by being mounted in or on a high-rigidity support or backing element.

It is also known to mold refractory and metal shapes by slip-casting. So, for instance, the U.S. Patent No. 4,341,725, issued on July 27, 1982, discloses a slip-casting process wherein a nucleating agent is added to the slip prior to the casting and to the subsequent freezing of the cast preform in order to keep the sizes of ice crystals forming in the cast preform during the freezing of the latter at a level sufficiently low to avoid structural damage to the

preform that would result if the sizes of the ice crystals were excessive. The only specific use that this patent describes for its method is in the context of making a simple tube of constant inner and outer diameters. Even though this patent mentions that other elements could also be produced by resorting to the same process, it should be evident that the sintered final products obtained by the process as disclosed in this patent, regardless of their shapes, would be totally unsuited for use as free abrasive grinding tools for use in high-precision applications, such as those encountered with optical components, if for no other reasons, then for their relatively high brittleness.

Last but not least, the commonly assigned U.S. Patent No. 4,975,225 discloses an approach to making solid substrates by first forming a porous sintered body or preform and then introducing an initially flowable material into the pores of such preform to completely fill such pores and solidify therein. However, this patent discloses only one use of this approach, namely, in the fabrication of mirror substrates, and contains no suggestion that such approach could or should be used for making other articles, and especially grinding and/or polishing laps.

Accordingly, it is the general object of the invention to avoid the disadvantages of the prior art.

More particularly, it is an object of the present invention to present a method of making relatively sturdy grinding or polishing tools, such as free abrasive or embedded abrasive laps, which method does not possess the disadvantages of the prior art methods of this type.

Still another object of the present invention is so to develop the method of the above type as to

improve the extent to which the tools made thereby satisfy the requirements placed on them.

It is yet another object of the present invention to devise a method of above type which results in grinding or polishing tools that are rigid enough, both locally and overall, to achieve excellent figure control of the workpieces acted upon by such tools at relatively high material removal speeds.

A concomitant object of the present invention is to provide a versatile grinding or polishing tool that has such characteristic properties as to satisfy the requirements placed on it better than previously proposed tools of this type throughout a wide range of operating conditions.

Disclosure of the Invention

In keeping with these objects and others which will become apparent hereafter, one feature of the present invention resides in a composite yet monolithic material removing lap that includes a sintered porous matrix of ceramic or metal material and a quantity of impregnating material substantially completely filling the pores of the sintered porous matrix preform at least throughout an effective region of the lap that is to come in contact with a workpiece to be acted upon by the lap. According to another aspect of the present invention, the above lap is manufactured by first forming an initial preform by filling a mold cavity with a dense slip consisting ceramic or metal particles in mixture with a liquid medium, then freezing the initial preform and freeze-drying the same to remove the liquid medium therefrom, followed by sintering the thus obtained dry preform only to such an extent that the larger ones of the particles are fused together but leave interconnected pores therebetween, and converting the thus obtained porous matrix preform into the lap by

bringing the porous matrix preform to a temperature above the melting point of the impregnating material, and contacting the porous matrix preform with a quantity of molten the impregnating material in such a manner that such molten impregnating material penetrates into the pores of the porous matrix preform at least to an extent needed to substantially completely fill the pores of an effective region of the lap that is to come in contact with a workpiece to be acted upon by the lap.

Brief Description of the Drawing

The present invention will be described in more detail below with reference to the accompanying drawing in which:

Figure 1 is a plan view of a grinding or polishing lap in accordance with the present invention showing an effective region of the lap;

Figure 2 is a cross-sectional somewhat enlarged view of a fragment of the lap taken along line 2 - 2 of Figure 1, in juxtaposition with a portion of a workpiece being acted upon by the lap;

Figure 3 is a further enlarged view showing a detail 3 - 3 of Figure 2 and especially the internal structure of the effective region of the lap as constructed for use in free abrasive grinding; and

Figure 4 is a view similar to that of Figure 3 but with the lap being constructed for use in embedded abrasive grinding or polishing.

Best Mode for Carrying Out the Invention

Referring now to the drawing in detail, it may be seen that the reference numeral 10 has been used therein to identify a grinding or polishing lap of the present invention in its entirety. The lap 10 is shown to have a configuration of a circular disk. As will

become apparent from a comparison of Figures 1 and 2, the lap 10 as illustrated is provided, at a region 11 of its exposed major surface 12 that faces the observer in Figure 1 of the drawing, with two orthogonal arrays of substantially equidistant grooves 13 and 14 which intersect each other and penetrate only to a certain depth, which corresponds to that of the region 11, below the exposed major surface 12 to thus subdivide the region 11 into a multitude of raised portions or mesas 15 of substantially square outlines. As shown in particular in Figure 2 of the drawing, the grooves 13 and 14 subdivide the exposed major surface 12 into respective exposed surfaces 16 of the mesas 15 which face a respective workpiece 20 to be polished or ground when lap 10 is in its position of use.

Having so described the depicted configuration of the lap 10, the internal structure thereof, and a currently preferred method by which such internal structure is obtained, will now be discussed first in general terms with particular reference to Figures 3 and 4 of the drawing, without initially differentiating between the lap structures destined for free abrasive grinding, on the one hand, and embedded abrasive grinding, on the other hand.

As a first step, a "green" preform of the lap 10 is produced by slip casting, of which an example is disclosed in the above-mentioned U.S. patents to which reference may be had for further details of the slip casting process as such. The expression "slip casting" is being used herein to indicate a process in which a pourable slip consisting of metal, ceramic, or carbon powders or mixtures of such powders and a liquid (usually water) is poured in a non-absorbent mold, the mixture is frozen, removed from the mold and eventually freeze-dried to obtain a "green-state" body ready for firing.

The powders contained in the slip used in the performance of the method of the present invention preferably consist of larger particles 17 and smaller particles 18 in intimate mixture with one another. The "green" preform obtained from the slip-casting process as described so far is then lightly sintered, that is, sintered only to such an extent that the smaller particles 18 melt and connect the larger particles 17 with one another to form a relatively stable, yet still quite brittle, porous matrix of the kind illustrated in Figure 3. After the thus sintered preform or matrix body of the lap 10 is obtained, it is contacted with a pore-filling or impregnating material 19 or 19' that is in its flowable or liquid state during the formation of the lap 10, in such a manner that the pore-filling material 19 or 19' penetrates or wicks into the pores or interstices present between the sintered particles 17 and 18, at least to such an extent as to permeate the region 11 but preferably to substantially completely fill the pores or interstices throughout the sintered preform, thus converting such preform into the lap 10.

The grooves 13 and 14 may be provided in the "green" preform during the slip-casting process, for instance as a result of the presence of ridges or ribs in the casting mold that penetrate into the internal space of the mold. However, the grooves 13 and 14 can also be formed at any later stage, such as after the sintering or even later, by resorting to a material removal operation, such as milling. Subsequently to the conversion of the sintered preform into the lap 10, the region 11 is machined to remove material from the mesas 15 and thus to form their exposed surfaces 16, mainly to give the exposed major surface 12 of the lap 10 its desired, such as planar, configuration and also

to improve the surface quality of the exposed surfaces 16 of the mesas 15.

The main difference between the impregnating materials 19 and 19' is that the material 19 becomes relatively hard after its introduction into the pores of the sintered preform, while the material 19' is relatively soft or compliant with respect to the matrix material at all temperatures encountered at the region 11 of the lap 10 during the use of the lap 10.

Example 1

A silicon carbide free abrasive lap of the type shown in Figure 3 was formed as follows:

A batch of casting slip was prepared by mixing the following materials in the quantities shown, and rolling in a jar mill for for about 27 hours:

Silicon Carbide powder (F-320)	5,773.8 g
Silicon Carbide powder (- 1.0 um)	4,220.0 g
Water	1,313.7 g
Sodium Silicate	34.8 g
Dimethyl Sulfoxide	205.3 g

The casting slip prepared as described above was introduced into a mold cavity of an assembled multipartite mold through a feed port, and the air displaced thereby escaped from the mold cavity through an escape port. The mold and the slip were vibrated both during the fill and for 15 minutes thereafter, to free entrapped air.

The still assembled mold and its contents were placed in a refrigerated compartment stabilized at -85°C and allowed to remain for about 30 minutes. The mold and its contents were subsequently removed from the refrigerated environment, and the mold portions were disassembled to free the frozen "green" preform.

The frozen preform was then allowed to equilibrate at a temperature of -85^{o}C for about 1 hour.

Thereafter, the frozen casting was converted in steps into the final product or lap 10 by being first placed in a chamber which was evacuated to approximately 100 um of Hg at room temperature. The vacuum pumping was continued for nearly 16 hours when the vacuum level discernibly increased to less than 50 um of Hg, indicating that the freeze-dying (sublimation) process had been substantially completed and that the casting could be considered dry. The dried casting was lightly sintered by subjecting it to 2050^{o}C in a partial pressure of argon atmosphere.

The thus partially sintered porous preform was filled with silicon by exposing it to molten silicon at 1750^{o}C in a partial pressure of 1 mm of Hg of argon. This filling procedure involved placing the sintered preform, with its mesa region at the bottom, on a layer of silicon powder supported on a heating plate, and gradually raising the temperature of both the preform and the heating plate, and thus of the silicon powder layer, to the temperature mentioned just above, resulting in melting of the pulverulent silicon and wicking of the thus molten silicon, due to the action of capillary forces, into the pores of the sintered matrix. Depending on the amount of the silicon material present in the silicon powder layer and on the magnitude of the capillary forces (which, in turn, depends on the pore sizes), and possibly on other parameters, such as temperature, the molten silicon may rise all the way to the top of the preform, or only a part of the way; in any event, however, the above parameters are selected and/or controlled in such a manner as to assure penetration of the molten silicon at least throughout the mesa region, this degree of

penetration being sufficient for the lap to be fully functional in many applications.

In some cases, it is advantageous to preheat the sintered preform, just prior to bringing the same in contact with the silicon, to a temperature close to or even above the melting temperature of silicon; this reduces the amount of time needed to achieve the melting of the silicon powder and its subsequent penetration into the sintered matrix in the protective atmosphere environment. In either case, after the penetration of silicon into the preform is completed, the thus obtained lap 10 is allowed or caused to cool, resulting in the solidification of the silicon 19 in the pores of the sintered silicon carbide matrix 17, 18, whereafter the region 11 can be ground to remove material from the surfaces 16 of the mesas 15 and thus to improve the quality of these surfaces 16.

Example 2

A composite silicon carbide/pitch lap of the type shown in Figure 4 of the drawing was formed by first following the above procedure up to and including the sintering of the preform. Thereafter, the interstices or pores of the thus partially sintered porous preform were filled with pitch in the following manner: first, the circumferential surface of the perform was covered by attaching aluminum foil or tape thereto, in order to avoid escape of pitch thereat during the pore-filling operation. Then the preform was heated to a temperature exceeding the melting temperature of the pitch (which, depending on the exact composition of the pitch within the composition range known to be suited for use in polishing or grinding operations, is in the range of about about 95 to 120^{o}C), placed on an upwardly facing surface of a heat sink bottom plate of aluminum with the mesa region being on top, and molten

pitch was poured onto and spread over the entire top region of the preform to flow into and through the pores of the sintered matrix. Any pitch reaching either the circumferentially arranged aluminum tape or foil, or the heat sink bottom plate, froze or solidified almost immediately upon contact, thus plugging the respective pores and preventing outflow of pitch therethrough, without interfering with the flow of the pitch into or through other internal pores. Finally, the thus pitch-permeated preform was allowed or caused to cool below the melting temperature of the pitch, resulting in solidification of the remainder of the pitch into the formation 19', and the preform was removed from the bottom plate and the circumferential tape or foil was stripped therefrom, thus making the preform ready for subsequent machining or other operations of the kind mentioned before.

Example 3

The procedure of Example 2 was followed in the making of a composite silicon carbide/lead lap, except that the sintered preform was brought up (such as preheated) to a temperature exceeding the melting temperature of lead (approximately to 375°C) prior to the pouring of molten lead onto and spreading the same over the top surface of the preform.

As a comparison of Figures 2 and 3 of the drawing will reveal, when a grinding operation is to be performed using the lap 10 of Example 1, the region 11 of the lap 10 is brought into contact, during the actual grinding operation, with a layer 22 of grit or abrasive particles 21 which are supported, either by themselves or in mixture with or suspension in a carrier medium such as a cooling medium or paste, on the surface of the workpiece 20 that is to be acted upon. The pressure exerted by the lap 10 on the layer

22 containing or consisting of the abrasive particles 21 causes such particles 21 to become displaced as the lap 10 moves along the workpiece 20, as a result of which the abrasive particles 21 abrade the material of the workpiece 20 from the surface of the workpiece that faces the region 11. The pressure exerted during the use of the lap 10 and/or the size of the particles 21 are then determinative of the depth of penetration of the abrasive particles 21 into the workpiece 20, and thus of the achieved surface quality of the latter.

On the other hand, it is advantageous, before using the lap 10 of either one of the Examples 2 and 3 to charge its region 11 with abrasive particles 21', for instance, by pressing the region 11 of the lap 10 with a predetermined force against a layer of such abrasive particles 21' that is supported on a support of a configuration generally conforming to that of the major surface 12. However, this abrasive particle charging may also take place automatically during the actual grinding or polishing operation in that a layer 22' of such particles 21, by themselves or in mixture with or suspension in a carrier medium such as a cooling medium or paste, is formed on the surface of the workpiece 20 that is to be acted upon, and the lap 10 is pressed against the layer 22'. In any event, the pressure exerted by the lap 10 on the respective layer, such as 22' of the abrasive particles 21' causes such particles 22' to become embedded in the region 11 of the lap 10, and more particularly in the relatively soft pore-filling material 19'. After the particles 21' have been so embedded in the region 11, the lap 10 can be used for polishing or grinding the surface of the workpiece 20 that faces the exposed surface 12 of the lap 10, in that the embedded abrasive particles 21' abrade the material of the workpiece 20 in a manner that can be perceived from Figure 4 of the drawing.

Here again, the pressure exerted during the use of the lap 10 and/or the size of the particles 21' are determinative of the depth of penetration of the embedded abrasive particles 21' into the workpiece 20, and thus of the achieved surface quality of the latter and, consequently, of the classification of the abrading operation either as a grinding operation or as a polishing operation.

In each case, the resultant article 10 was a composite yet, in effect, monolithic, relatively high stiffness structure that, however, because of the presence of the pore-filling material, such as silicon, tar pitch, lead or the like, at least in the mesa region 11 of the lap 10, not only has been rid of the deleterious effects of the original brittleness of the sintered porous preform but also has become better able to cooperate with various sizes of the abrasive particles 21 or 21' to achieve the desired degree of abrasion during each grinding or polishing pass or phase. Moreover, the thus obtained lap 10 presents an almost ideal combination of the advantageous properties of the two materials constituting the same, that is, the high stiffness and high thermal conductivity of the silicon carbide that results in excellent figure control, with the higher pliability of the respective impregnating material that results in an improved entrainment of the abrasive particles 21 or 21', while avoiding the detrimental effects of such materials.

While the present invention has been illustrated and described as embodied in a particular constructions of silicon carbide/impregnating material composite laps for use in abrasive grinding, polishing or similar material-removing operations, it will be appreciated that the present invention is not limited to these particular examples; rather, the scope of protection of

the present invention is to be determined solely from the attached claims.

Claims

1. A method of manufacturing a composite yet monolithic abrasive material-removing lap, comprising the steps of

forming an initial preform, including filling a mold cavity with a dense slip constituted of ceramic or metal particles in mixture with a liquid medium;

freezing the initial preform;

freeze-drying the initial preform to remove the liquid medium therefrom;

sintering the thus obtained dry preform only to such an extent that the larger ones of the particles are fused together but leave interconnected pores therebetween; and

converting the thus obtained porous matrix preform into the lap, including contacting the porous matrix preform with a quantity of impregnating material, at a temperature at which the impregnating material is flowable, in such a manner that such flowable impregnating material penetrates into the pores of the porous matrix preform at least to an extent needed to substantially completely fill the pores of an effective region of the lap that is to come in contact with a workpiece to be acted upon by the lap.

2. The method as defined in claim 1, wherein said impregnating material is silicon; and wherein said converting step includes bringing the temperature of the porous matrix to above the melting point of silicon prior to the performance of said contacting step.

3. The method as defined in claim 1, wherein said impregnating material is of the type that is pliable at the operating temperatures of the lap; and further comprising the step of embedding abrasive particles in

the impregnating material at the effective region of the lap, including pressing the effective region and the abrasive particles against one another.

4. A composite yet monolithic abrasive material-removing lap, obtained by a method comprising the steps of

forming an initial preform, including filling a mold cavity with a dense slip constituted of.ceramic or metal particles in mixture with a liquid medium;

freezing the initial preform;

freeze-drying the initial preform to remove the liquid medium therefrom;

sintering the thus obtained dry preform only to such an extent that the larger ones of the particles are fused together but leave interconnected pores therebetween; and

converting the thus obtained porous matrix preform into the lap, including contacting the porous matrix preform with a quantity of an impregnating material, at a temperature at which the impregnating material is flowable, in such a manner that such impregnating material penetrates into the pores of the porous matrix preform at least to an extent needed to substantially completely fill the pores of an effective region of the lap that is to come in contact with a workpiece to be acted upon by the lap.

5. The lap as defined in claim 4, wherein said impregnating material is silicon; and wherein said converting step of said method includes bringing the temperature of the porous matrix to above the melting point of silicon prior to the performance of said contacting step.

6. The lap as defined in claim 4, wherein said impregnating material is of the type that is pliable at the operating temperatures of the lap; and wherein the method further comprises the step of embedding abrasive particles in the impregnating material at the effective region of the lap, including pressing the effective region and the abrasive particles against one another.

7. A composite yet monolithic abrasive material-removing lap, comprising

a sintered porous matrix of ceramic or metal material; and

a quantity of a solidified impregnating material substantially completely filling the pores of the sintered porous matrix preform at least throughout an effective region of the lap that is to come in contact with a workpiece to be acted upon by the lap.

8. The lap as defined in claim 7, wherein said impregnating material is silicon.

9. The lap as defined in claim 7, wherein said impregnating material is of the type that is pliable at operating temperatures of the lap; and further comprising a layer of abrasive particles embedded in the impregnating material at the effective region of the lap.

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fig. 1

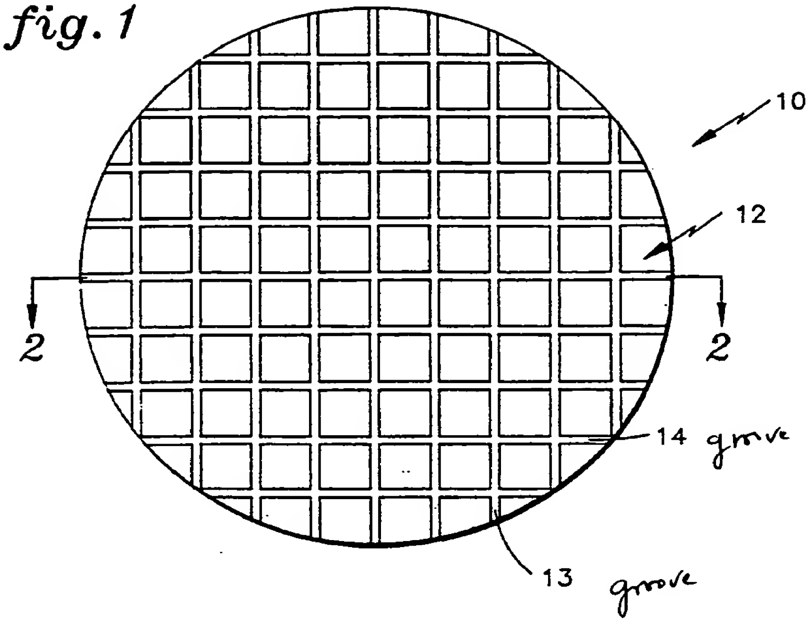


fig. 2

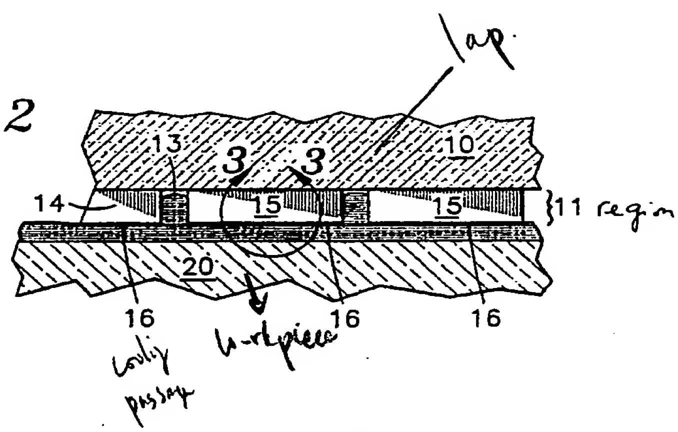
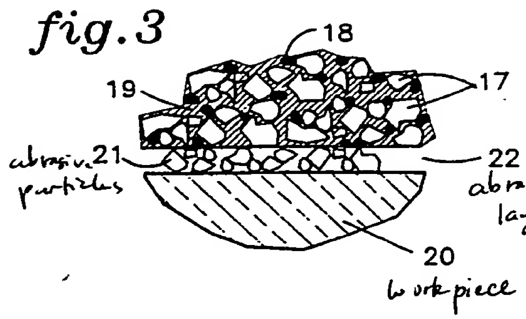


fig. 3



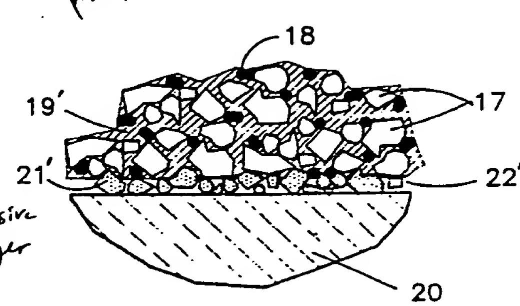


fig. 4

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fig.1

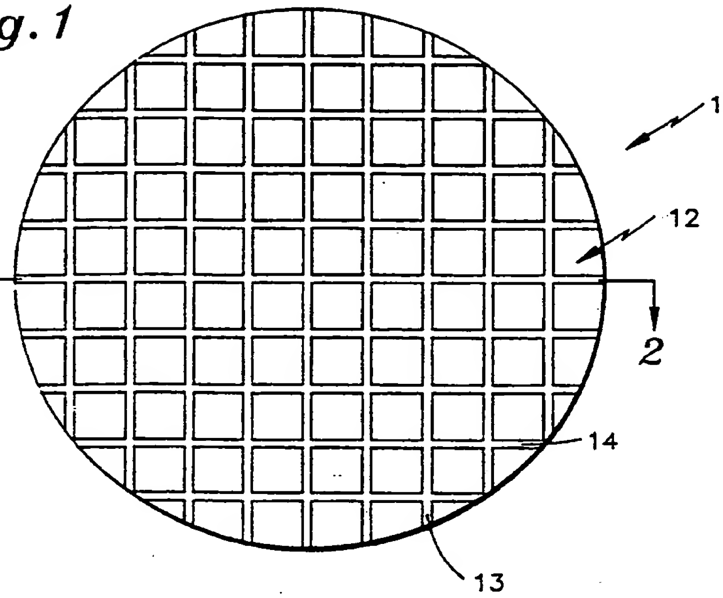


fig.2

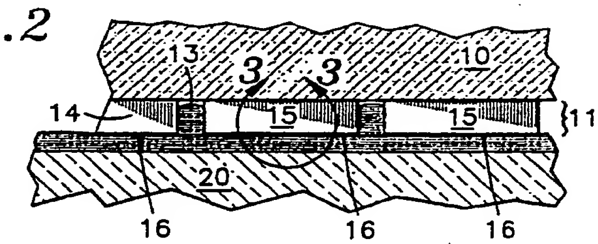
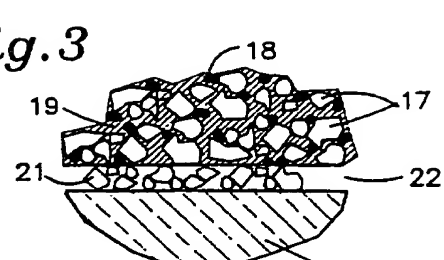


fig.3



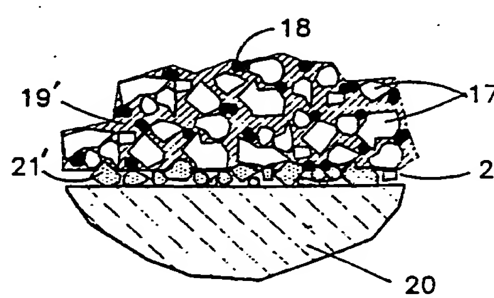


fig.4